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DX-Center-Like Traps in AlGsSb

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Characteristics of electron-traps in Te-doped AlGaSb epitaxial layers were investigated by DLTS, C-V, photocapacitance, and Hall effect measurements in a wide range of Al composition. Strong composition dependence, predominance of the trap concentration, and differences among activation energies for electron capture, thermal emission and optical electron ionization were observed. Persistent photoconductivity was also observed in the Hall effect measurement. The electron-traps were also found in Se-doped AlGaSb. The proposed models for the origin of the DX-center are examined.

1. Introduction

In order to find the clue to the origin of high concentration electron-trap, i.e., the DX-center in AlGaAs[1], the donor-related deep electron-traps in Te-doped AlGaSb on GaSb substrates have been investigated using DLTS (deep level transient spectroscopy), C-V (capacitance-voltage), photocapacitance, and Hall effect measurements[2,3]. The AlGaSb alloy was taken because its band structure is similar to that of AlGaAs, and in GaSb the energy separation between Γ- and L-valley is as small as 0.078-0.092eV[4] and then the effect of the higher bands on the DX-center should be large even in GaSb. Thus, band related models[5-7] for the origin of the DX-center can be examined by this alloy system, and also general features of deep electron-traps in alloy semiconductors can be elucidated.

In this paper, we will report the DLTS, C-V, photocapacitance, and Hall effect measurements of Te-doped AlGaSb Schottky diodes and describe the characteristics of the deep electron-traps in Te-doped and Se-doped AlGaSb.

2. Experimental Procedure

2.1 Sample Preparation

The AlGaSb samples used for DLTS and C-V measurements were grown on Te-doped GaSb substrates by liquid phase epitaxy at 500°C. Schottky barriers were fabricated on Te-doped and Se-doped epilayers by evaporating a gold film. In order to electrically isolate the epilayers from the conductive GaSb substrates for Hall effect measurements, undoped p-type AlGaSb was first grown on GaSb substrate and then Te-doped AlGaSb on it.

2.2 Measurements

DLTS measurements were performed in the temperature range from 80 to 300K. Because of the high concentration of the electron-traps, it was necessary to use C^2-DLTS for the samples with x>0.3 A long injection pulse (~25ms) was required to fill the traps. The sampling was performed both in the emission pulse range and the injection pulse range for the measurements of activation energies for thermal emission and electron capture. The donor concentrations were measured by C-V profiling.

Photocapacitance measurements were performed to determine the optical ionization energy to remove electrons from the electron-traps to the conduction band. Since at low temperatures the thermal emission rate and capture rate are negligible, the concentration of occupied deep electron-traps n_{dd} is given by[8)]

$$n_{dd}(t)=N_{dd}\exp(-\Phi\sigma_n^o t) \qquad (1)$$

where Φ is the optical intensity, σ_n^o is the optical cross-section. N_{dd} is the concentration of the deep trap.

The samples were also characterized by Hall effect measurements using van der Pauw technique at a magnetic field of 5kG and in the temperature range 77-300K.

3. Results

As it is already reported[3)], no deep electron-traps were detected in Te-doped $Al_xGa_{1-x}Sb$ with x<0.2. The concenration of deep electron-traps increased steeply with x in the region of 0.3-0.5, and saturated for x>0.5. Activation energies for thermal emission and cross-sections are listed in Table 1. Activation energies for electron capture of x=0.4 and x=0.5 were measured as 0.32 and 0.35eV, respectively.

Figure 1 shows the dependence of the donor concentration in Te-doped $Al_{0.5}Ga_{0.5}Sb$ on the Te atom fraction in liquids (growth solution). It can be seen that the donor concentration linearly increases with

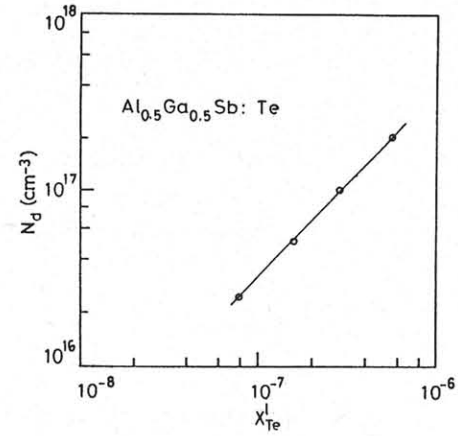

Fig. 1 Dependence of the donor concentration on the Te atom fraction in liquids.

increasing Te atom in liquids. Because majority of the donors become deep electron-traps at x=0.5, the deep trap concentration also increases linearly with the Te atom fraction in liquids. The dependence indicates that the deep electron-traps are donor-related.

Figure 2 shows a normalized electron photoionization cross-section as a function of photon energy for Te-doped $Al_{0.5}Ga_{0.5}Sb$ at 100K. The solid line in Fig. 2 is a theoretical fit[9)] to the data. The optical ionization energy (E_n) was obtained as 0.86eV from the curve fitting.

The temperature dependence of free electron concentration revealed for several Al compositions by Hall effect measurement are shown in Fig. 3. The thermal activation energies are indicated in Fig. 3.

For Te-doped AlGaSb with x≥0.3, the

Table 1 Activation energies for thermal emission (E_e) and capture cross-sections in Te-doped $Al_xGa_{1-x}Sb$ with several x. At x below 0.2 no deep traps were detected.

x	0.3	0.4	0.49	0.61	0.72	
E_e(eV)	0.39	0.43	0.48	0.49	0.49	0.51
$\sigma_t(cm^2)$	4.1×10^{-13}	2.1×10^{-11}	1.3×10^{-11}	1.2×10^{-12}	2.9×10^{-13}	5.1×10^{-13}

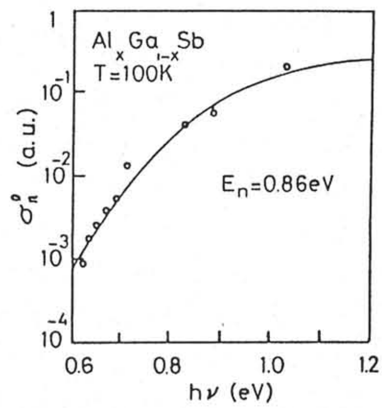

Fig. 2 Normalized electron photoionization cross-section as a function of photon energy for $Al_{0.5}Ga_{0.5}Sb$ at 100K.

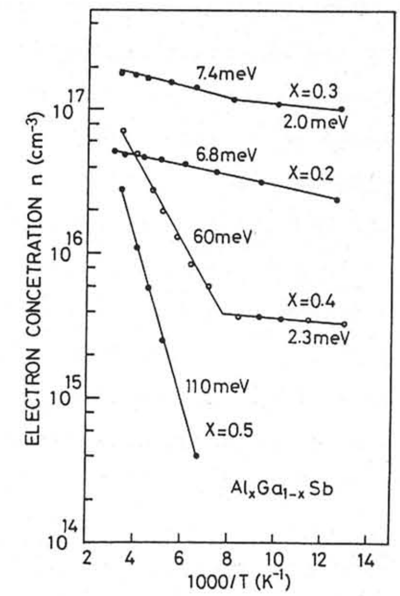

Fig. 3 Temperature dependence of free electron concentration for several Al compositions.

electron concentration and mobility were exposed to white light at 77K. The increased values were persistent after the light was turned off. The changes in electron concentration and of mobility due to illumination are listed in Table 2.

In Te-doped AlGaSb, electron-traps were not detected with Al composition up to 0.2. However, deep traps with E_e=0.24eV and 0.37eV in Se-doped $Al_{0.1}Ga_{0.9}Sb$ and E_e=0.35eV in $Al_{0.3}Ga_{0.7}Sb$ were detected by DLTS. The depths of the traps were different from that in Te-doped AlGaSb at the same Al composition.

4. Discussions

The distinct features of DX-center in AlGaAs are: a) a large difference between the thermal and optical activation energy, b) persistent photoconductivity (PPC) at low temperatures, c) a very small capture cross-section at low temperatures, d) linearity between the deep trap concentration and donor concentration. In the previous papers[2,3], two of these features, e.g., the persistent photoconductivity and optical activation energy, were not yet observed. In the present work we could successfully conduct the Hall effect measurement and verify the existence of PPC in Te-doped

Table 2 Electrical properties of Te-doped AlGaSb in the dark and after illumination.

	300K		77K			
			Dark		Persistent	
x	n (cm^{-3})	μ ($cm^2V^{-1}s^{-1}$)	n (cm^{-3})	μ ($cm^2V^{-1}s^{-1}$)	n (cm^{-3})	μ ($cm^2V^{-1}s^{-1}$)
0.2	$5.0x10^{17}$	411	$2.3x10^{17}$	876	$2.3x10^{17}$	976
0.3	$8.7x10^{17}$	197	$5.1x10^{17}$	288	$6.8x10^{17}$	296
0.4	$8.4x10^{17}$	182	$3.8x10^{17}$	91.3	$7.0x10^{17}$	208
0.5	$4.1x10^{17}$	119	---	---	$4.1x10^{17}$	170

$Al_xGa_{1-x}Sb$ with x≧0.3. Thus, all of these features for the DX-center have been observed for the deep traps in Te-doped AlGaSb. It can be claimed that the deep traps in Te-doped AlGaSb arise from the same origin as the DX-center in AlGaAs.

Considering the energy separation between the Γ- and L-band minima, and the effective mass in L-band minima, the deep electron-traps should be detected even in GaSb if the DX-center is simply a donor associated with L-band.

The deep traps in Te-doped AlGaSb can not be explained by the band crossing of Γ- and L-band, since electron traps were not detected at x=0.2 where the Γ- and L-band cross.

Observation of deep electron-traps in low Al composition of Se-doped AlGaSb seem to support the model proposed by Yamaguchi[10] that the origin of the DX-center is the donor atom itself.

4. Summary

All of the experimental results observed in Te-doped AlGaSb strongly imply that the deep traps in Te-doped AlGaSb arise from the same origin as the DX-center in AlGaAs.

The models for the origin of the DX-center as donors associated with L band and that of Γ- and L-band crossing are not suitable to explain the behavior of the deep levels in Te-doped AlGaSb.

The deep levels with different depths from that in Te-doped AlGaSb were also found in Se-doped AlGaSb.

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